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# Factors affecting the growth and condition of mussels *(Mytilus edulis L.)*

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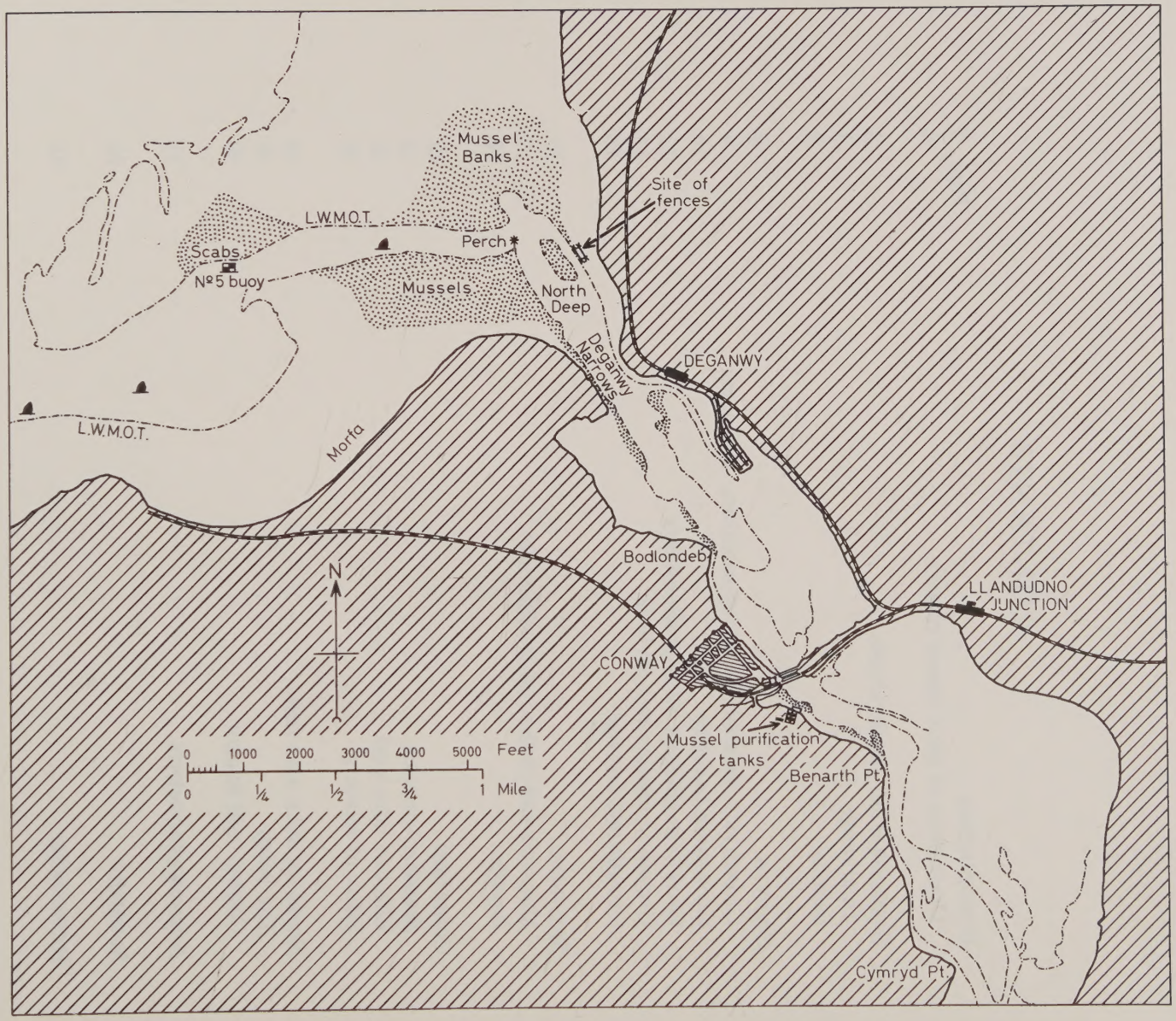



Frontispiece. *Chart of the Conway estuary showing the positions of the mussel grounds and the places mentioned in the text.*

# INTRODUCTION

It has been known for a long time that mussels exposed to the air by the tide for long periods, or to strong wave action, have a very low growth rate (Fox and Coe, 1943; Baird and Drinnan, 1957). These mussels, removed to a sheltered area below low-water mark, immediately begin to acquire the characteristics of their new environment and develop a much higher growth rate (Scott and Baxter, 1906). There are many other characteristic differences between the "bank" mussels and the sublittoral mussels, which affect their commercial value. Bank mussels typically have very thick shells (Baird and Drinnan, 1957) of an unpleasant slate blue appearance, due to the removal of the periostracum by abrasion, and they are frequently completely encrusted with barnacles (*Balanus balanoides*) which themselves have a dirty grey appearance. The mussels rarely attain a large size, and the meats are much thinner. The mussels that are rarely uncovered by the tides have very much smoother and thinner shells of a pleasant shiny black or tortoiseshell colour. They are less heavily encrusted with barnacles, and the barnacles themselves (*Balanus crenatus*) are smooth and white and succeed in enhancing the appearance of the mussel. These mussels are known in the Birmingham market (probably the biggest in the United Kingdom) under the misnomer "rock" mussels and there is a heavy and unsatisfied demand for them. The market demand is for large mussels, about $2\frac{1}{2}$ inches or more in length, although the best condition is usually found at a length of about 2 inches (Baird, 1958).

Heavy settlements of mussels occur in the intertidal zone. When this settlement is dense, the mussels form mud banks through the deposition of faeces and pseudofaeces and from silt settling out of the water flowing over them. These banks build up quickly where the tidal flow is not too fast, and the mussels are consequently raised still higher in the intertidal zone. Ashcroft (1898) reported mussel spat settling on bare gravel in the River Ribble, and within three years the mussels had accumulated a bank of mud ten feet in depth. During mussel-relaying experiments at Bangor mussels relaid in the River Ogwen were observed by the author to have built up a mud bank three feet in height within two years. Above half-tide level growth practically ceases, presumably due to the using up of food reserves during normal metabolic activity while the mussels are uncovered and unable to feed (Baird and Drinnan, 1957).

By far the greater part of the mussels sold in the United Kingdom are fished directly from the banks by hand, only a small part of the total catch being raked from sublittoral areas. Naturally, where the mussels are fished by hand, the higher in the tidal zone they are found, the longer is the time available to the fishermen for gathering, but also, unfortunately, the poorer is the quality of the mussels gathered.

Relaying of the bank mussels lower down the shore has been strongly advocated on many occasions over the years, but it has in fact proved very difficult to persuade fishermen to adopt this simple cultural routine. This is understandable in a free fishery where the fishermen have no claim to the mussels laid and they may well be relaying for the benefit of a competitor who has himself not done any relaying. In areas where the fishermen have their own plots, either by leases or acknowledged prescriptive rights, relaying and cultural routines are undertaken, notably in the north Norfolk harbours and at Teignmouth, Devon.

The Dutch mussel industry, the largest and most highly developed in the world, with an annual output of the order of 50 000 tons, is based entirely on the relaying of mussels, soon after settlement, on to sublittoral grounds for growth and fattening.

The investigation described below was undertaken to find some measure of the effect on mussels of relaying them in varying conditions in an estuary, and to increase our knowledge of the suitability of the existing mussels in the Conway estuary as a source of raw material for the development of cultural routines. Some experiments were also done at Bangor, N. Wales, and in the Wash on the east coast of England.

## DESCRIPTION OF THE CONWAY ESTUARY

The part of the Conway estuary with which this paper is concerned is shown on the map (Frontispiece). The river is tidal for approximately 12 miles above Conway. The channel at low water is narrow, and at spring tides depths vary from 40 ft at the Deganwy Narrows to about one or two feet at Bodlondeb Point and at the Perch. The Conway catchment area measures about 230 sq. miles, with an average annual rainfall of 80-90 inches in the upper reaches, falling to 30-40 inches at the river mouth. During periods of heavy rainfall, or when snow is melting on the mountains, very large quantities of fresh water come down the river and the salinity is substantially reduced in the estuary.

The littoral part of the area under discussion is mainly sandy or composed of firmly packed stones, but when mussel beds develop the substratum becomes covered with a layer of mud. Larger boulders occur in the North Deep (a bight to the south-east of the Perch), but sublittorally the bottom is sandy, stony, rocky, or (in one or two limited areas) muddy.

The distribution of mussels in 1959 is shown on the Frontispiece. In general the major settlements appear to occur on the banks, although substantial sublittoral settlements have been noted from time to time. All measurements for growth and condition were made on mussels taken from within the area of natural settlement and survival, except for one series of growth experiments where mussels were placed in cages half a mile further up the estuary than they naturally occur.

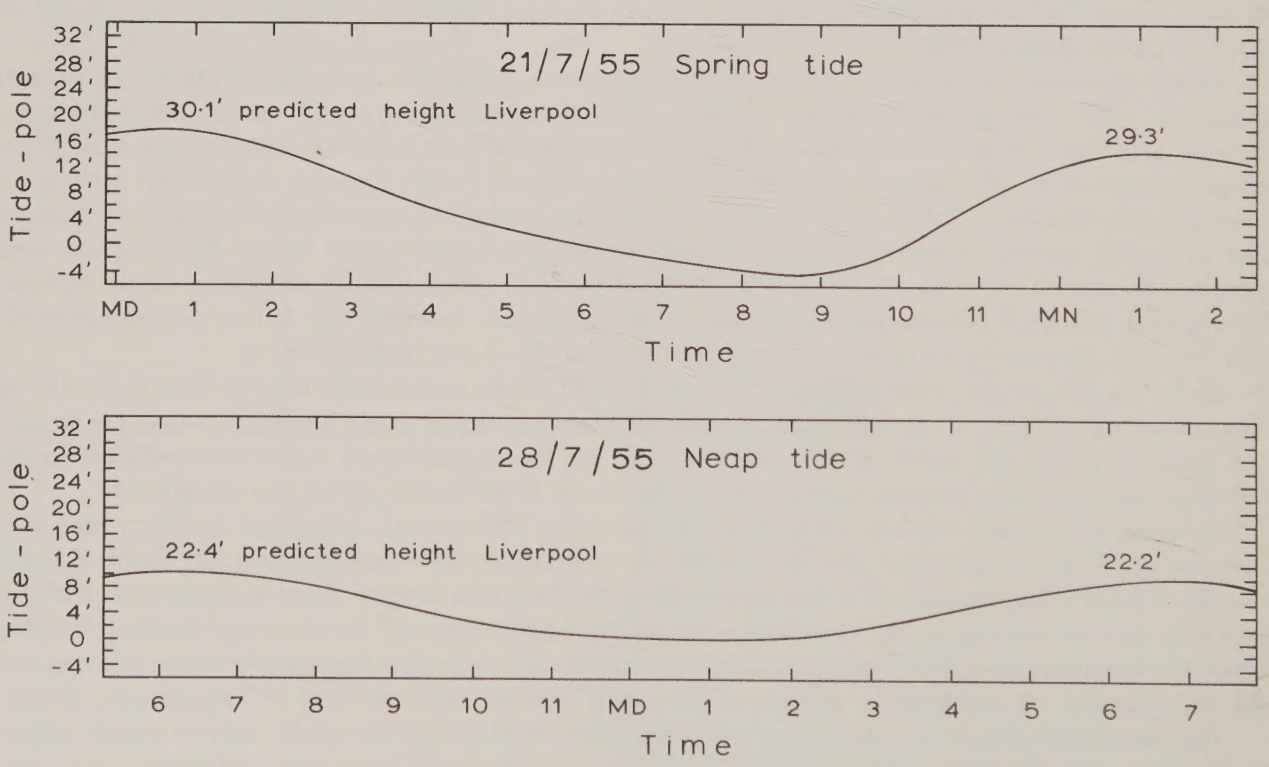



Fig. 1. *Spring and neap tide recordings made with a pressure-operated recorder sited below the Mussel Purification Tanks, Conway.*

# HYDROGRAPHIC OBSERVATIONS

## TIDAL RANGE

A hydrostatic pressure-operated tidal recorder was set up at the Mussel Purification Tanks and from the tracings a percentage exposure curve was derived. Exposure in this context means exposure of the mussels to air, and the actual tidal levels were determined by reference to a tide pole set up nearby. A spring tide and a neap tide recording are reproduced in Figure 1 and it can be seen that on a spring tide the curve is not symmetrical, due to the position of the recording site in the estuary. A site on the open sea would yield a trace showing a nearly symmetrical curve, with a low water approximately midway between two high waters. Recordings made at successively higher points up an estuary show a modification of the normal curve, with the ebb period becoming progressively longer and the flood correspondingly shorter. The time of high water is not affected appreciably, but the time of low water is considerably delayed. This is due to the low-water level at sea being below what we may call the "basic river level" of the estuary at the point under consideration; consequently the ebb at this point continues after the time of low water at sea, and the flood does not start until the level of the incoming tide reaches the river bed at this point. This results in the long period of steady ebb shown in the spring-tide recording in Figure 1. The neap-tide record does not show this phenomenon because, although the "basic river level" at this point is above low water of spring tides, it is not above low water of neaps. Figure 2, derived from a 14-day cycle of spring and neap tides, shows the percentage of time that any level on the beach is exposed to the air.

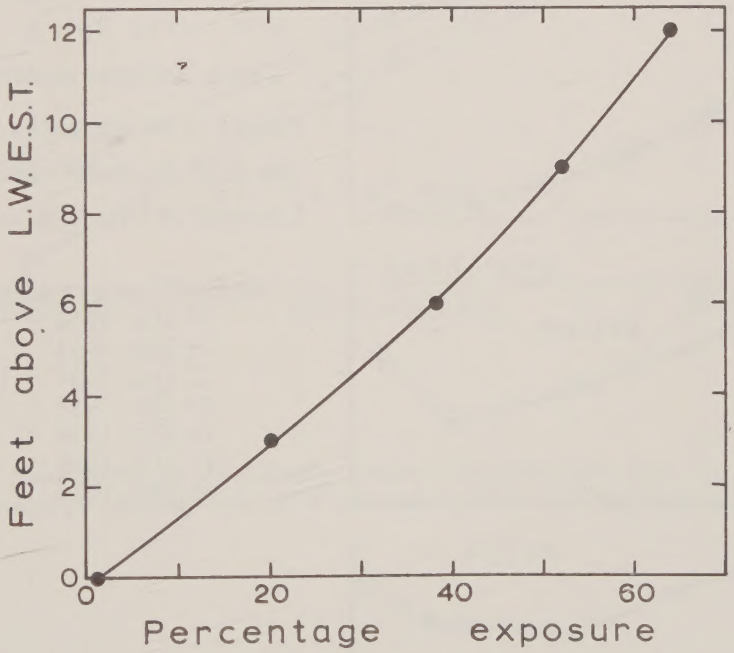



Fig. 2. *Curve showing percentage exposure of mussels to air, related to tidal level; derived from a 14-day cycle of spring and neap tides recorded below the Mussel Purification Tanks, Conway.*

## SALINITY

In the rules for operating the Mussel Purification Tanks at Conway, it is laid down that purification must cease when the specific gravity of the water available is below 1·016 (a salinity of 19‰ at 7°C). This allows a margin of safety, as it has been found that while normal functioning of mussels takes place at a specific gravity of 1·014, it ceases at about 1·010 to 1·012 (Dodgson, 1928).

The Mussel Purification Tanks are situated about 2 miles up the estuary, not far below the upper limit at which mussels occur. It has been found on several occasions that when periods of heavy rain coincide with neap tides the specific gravity does not rise above 1·012 at any stage of the tide. If at high water the salinity does not reach a figure high enough to permit functioning of the mussels, they remain closed for two or three days until the tides increase again. This presumably accounts for the fact that mussels do not occur much higher up the river.

The tidal range at Conway is about 20 ft (6 m) on spring tides and about 10 ft (3 m) on neap tides; high water of spring tides occurs at about midday and midnight, and high water of neap tides at about six o'clock in the morning and evening. There is a high rate of tidal flow in many parts of the estuary, and the depths are very variable, so that a fairly thorough mixing of bottom and surface water occurs.

A number of salinity measurements were made at various points in the estuary and at various stages of the tide, in order to get an overall picture of the salinity gradients both vertically in the water and horizontally up and down the estuary. Where possible, three samples (surface, 3 ft (0·9 m) below the surface, and bottom) were taken at each station. The 3 ft and bottom samples were taken by means of a weighted and corked bottle; the cork was pulled out at the required depth. The salinity was calculated from the specific gravity and temperature readings.

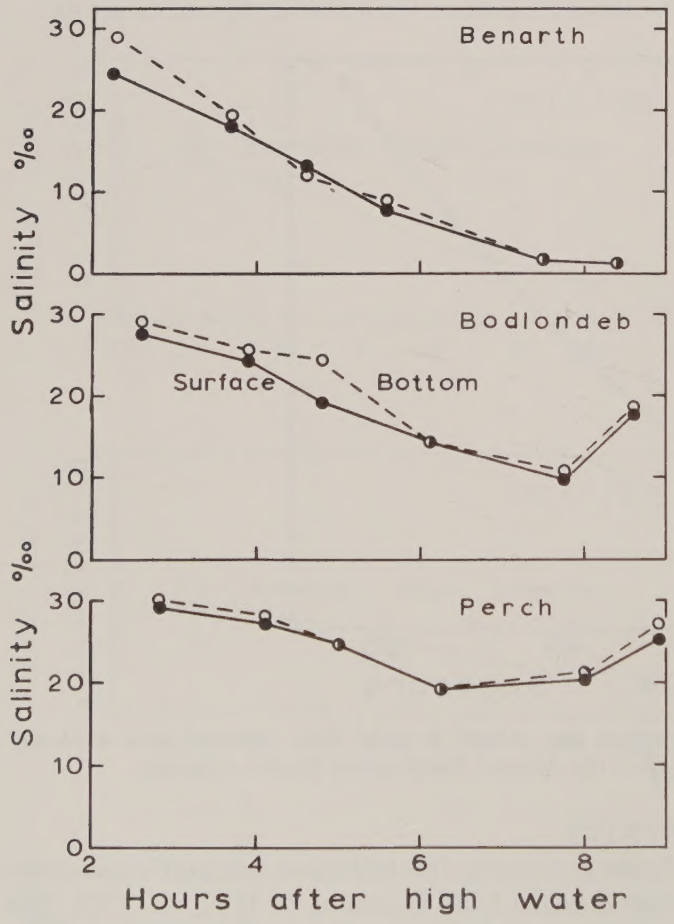



Fig. 3. *Salinities at three points in the Conway estuary at the approach to low water on the neap tide of* 16 *December* 1954. (*Predicted height at Liverpool* 24·6 *ft. High water was at* 0632 *hours*).

*Rainfall* (*inches*) *during previous* 7 *days*

| | |
|---|---|
| 10 Dec. 1954 | — |
| 11 Dec. 1954 | Trace |
| 12 Dec. 1954 | 0·06 |
| 13 Dec. 1954 | |
| 14 Dec. 1954 | 0·03 |
| 15 Dec. 1954 | — |
| 16 Dec. 1954 | — |

Figure 3 shows the surface and bottom salinities at three points in the river over a period of six hours before and up to low water. The 3 ft samples were very similar to the surface samples. Benarth is near the upper limit of mussels in the estuary, and the Perch is at about the centre of distribution. Rainfall over the preceding seven days is shown in the caption to the figure and it can be seen that even when the rainfall has been extremely low the salinity at Benarth drops almost to zero at low water.

Figure 4 is derived from Figure 3 and shows the salinity gradient between the three points at four, six and eight hours after high water. At all these stages of tide the gradient is considerable, but becomes steepest near the low-water period.

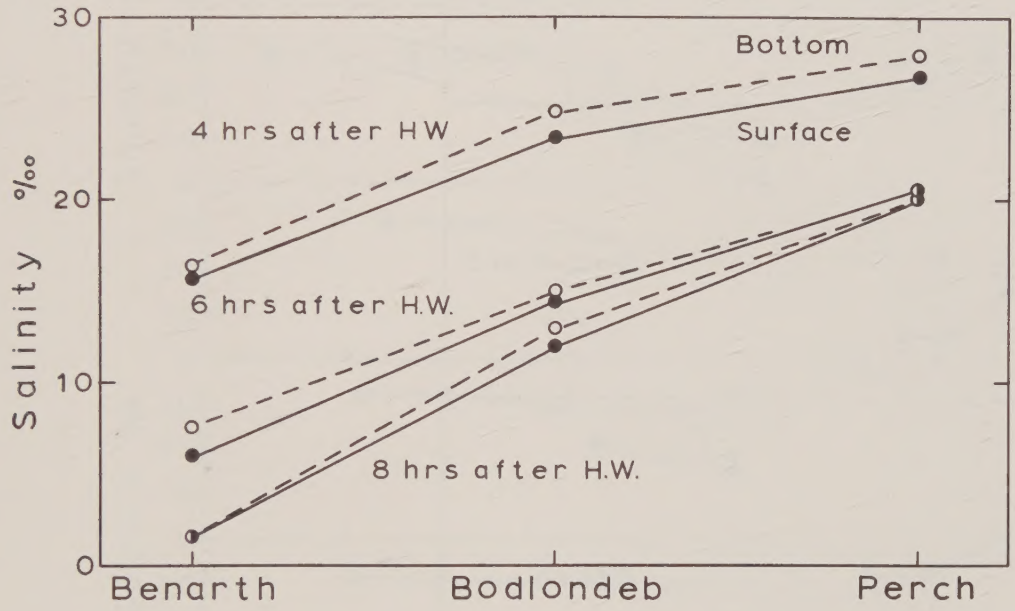
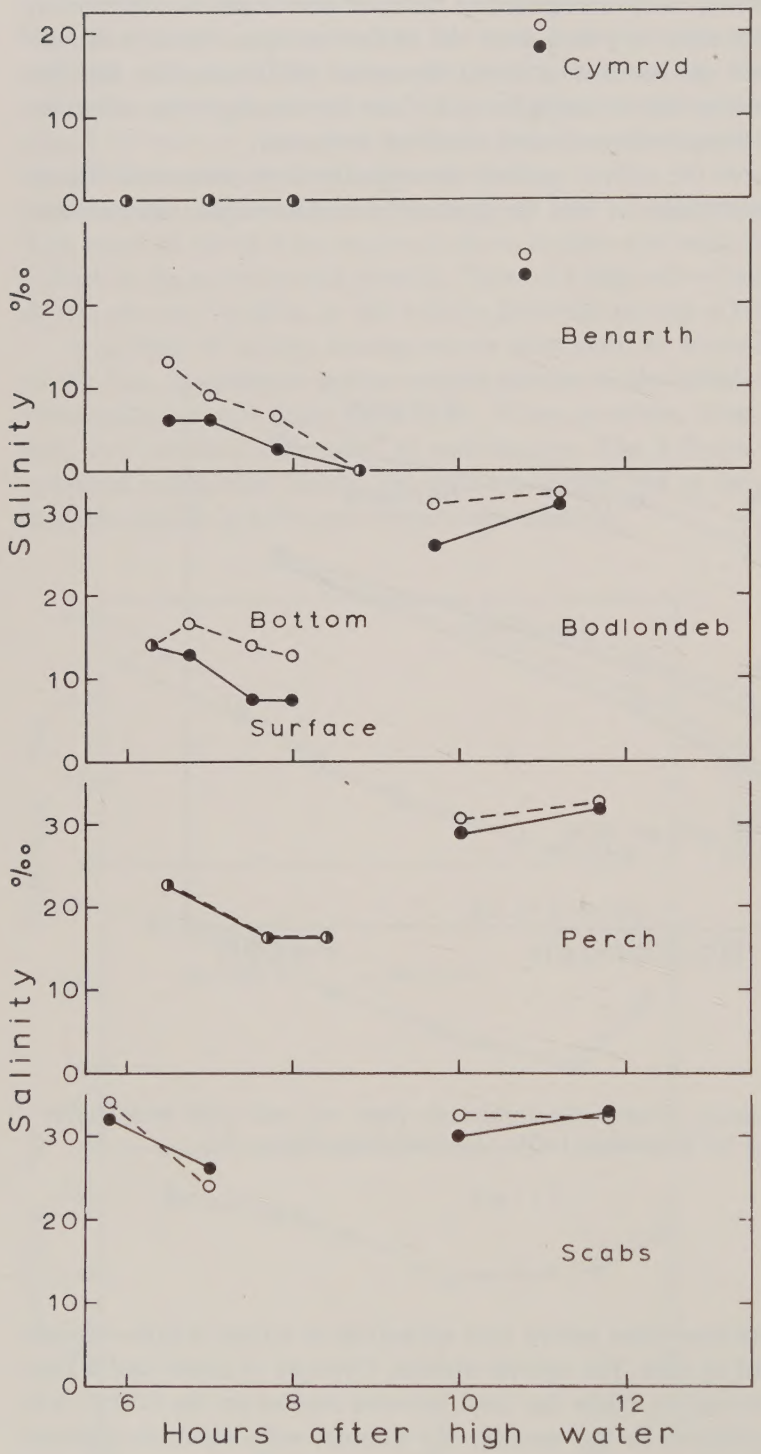



Fig. 4. *Salinities at three points in the Conway estuary simultaneously four, six and eight hours after high water on the neap tide of* 16 *December* 1954. (*Derived from Figure* 3.)

Figure 5 shows the salinity readings for the low-water period on a spring tide at a time of little rainfall, the number of stations having been increased by two. The upriver station, Cymryd, is about half a mile upriver of the upper limit of the mussel distribution, while the most seaward station (at the Scabs) is at about the seaward limit of the mussel distribution in the estuary. No samples were taken at Cymryd between 8 and 11 hours ebb, but it is certain that zero salinities would have continued at least to $8\frac{3}{4}$ hours ebb, at which time salinities had not started to rise at the Benarth station. In spite of the small amount of rain the salinity dropped to zero at Benarth, which is well within the mussel zone, showing that at low water of spring tides the water remaining is river water.




*Rainfall (inches) during previous 7 days*

| | |
|---|---|
| 25 Aug. 1954 | Trace |
| 26 Aug. 1954 | — |
| 27 Aug. 1954 | — |
| 28 Aug. 1954 | 0·03 |
| 29 Aug. 1954 | |
| 30 Aug. 1954 | 0·04 |
| 31 Aug. 1954 | — |

Fig. 5. *Salinities at five points in the Conway estuary over low water on the spring tide of* 31 *August* 1954, *in a period of little rain.* (*Predicted height at Liverpool,* 27·9 *ft. High water was at* 0102 *hours.*)

Figure 6 is a record of the salinity during the hours after high water of a spring tide in a period of little rain. The drop in salinity is seen to be much more rapid at the upriver stations than it is at the seaward end of the estuary.

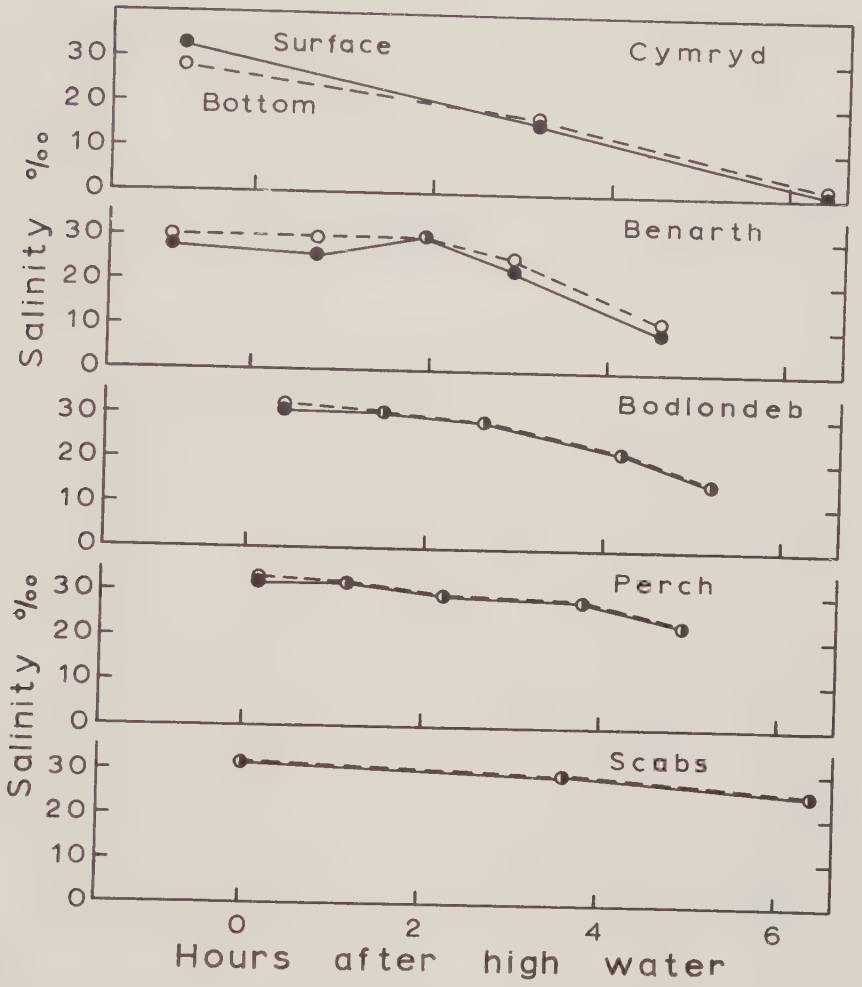



Fig. 6. *Salinities at five points in the Conway estuary over high water on the spring tide of* 31 *May* 1954, *in a period of little rain.* (*Predicted height at Liverpool,* 28·5 *ft. High water was at* 1037 *hours.*)

| *Rainfall (inches) during previous 7 days* | |
|---|---|
| 25 May 1954 | 0·02 |
| 26 May 1954 | 0·06 |
| 27 May 1954 | 0·18 |
| 28 May 1954 | 0·60 |
| 29 May 1954 | 0·28 |
| 30 May 1954 | |
| 31 May 1954 | — |

Figure 7 shows the salinity during the period over low water of a neap tide after a time of fairly heavy rainfall. At the Benarth station the salinity was at practically zero for at least 3½ hours. The slow tidal flow of the neap tides, combined with fairly heavy rainfall, produced at the Scabs station the only appreciable stratification that occurred during the whole series of observations.

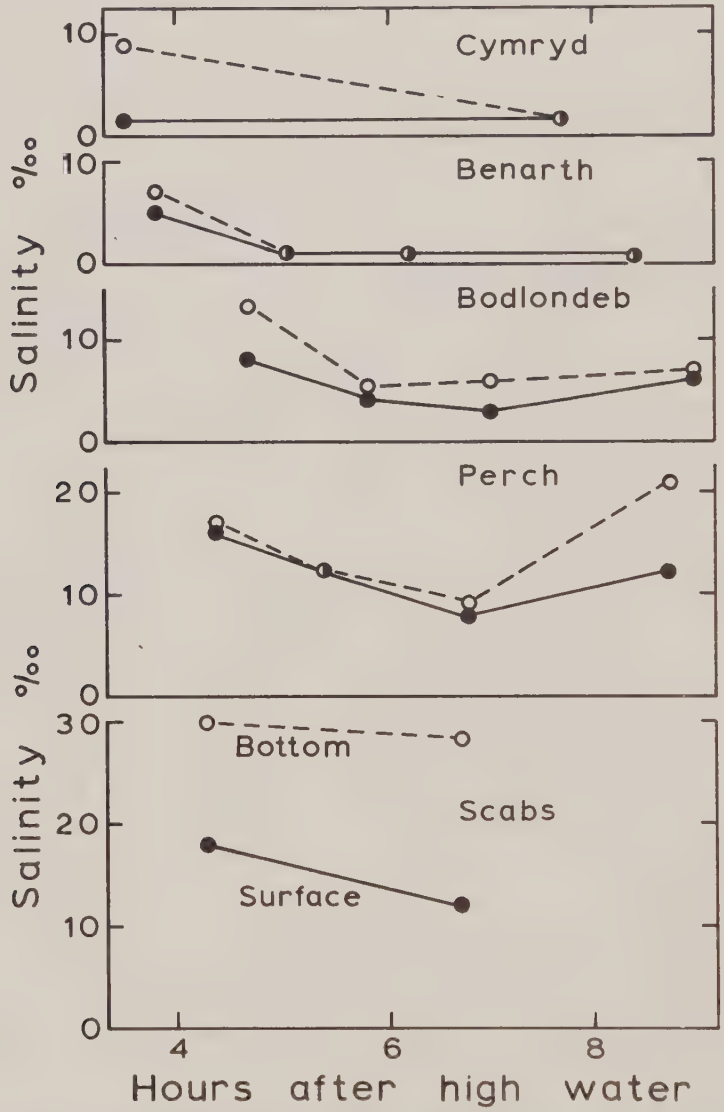



Fig. 7. *Salinities at five points in the Conway estuary over low water on the neap tide of* 10 *June* 1954, *after a period of heavy rainfall.* (*Predicted height at Liverpool*, 22·9 *ft. High water was at* 0642 *hours*).

| *Rainfall* (*inches*) *during previous* 7 *days* | |
|---|---|
| 4 June 1954 | 0·04 |
| 5 June 1954 | 1·02 |
| 6 June 1954 | |
| 7 June 1954 | 0·26 |
| 8 June 1954 | 0·16 |
| 9 June 1954 | 0·17 |
| 10 June 1954 | 0·10 |

Summarizing, it can be seen that very low salinities persist for a longer period at low water of neap tides than on spring tides, and this appears at first sight to be inconsistent with the tidal record observations. On spring tides, however, a much greater volume of seawater enters the estuary. High rates of tidal flow cause a fairly complete mixing of the fresh and salt water in the estuary and this large volume of mixed water will not all have run out past the bridges before the flood reaches the mussel tanks again. That this is so is demonstrated by the very slow decline in water level at the mussel tanks for some hours before absolute low water of a spring tide. On the neap tides, a much smaller volume of seawater has entered the estuary; thus the proportion of fresh water is far higher and the salinities fall to, and remain at, a lower level for a longer time.

From the scale of the tidal recordings it is difficult to determine at what point the ebb is lengthened, but from the low level to which the salinity records drop it is obvious that at neap tides the basic river level is at about the level of low water at the Mussel Tanks. If the basic river level were above the level of low water of neap tides at this point, a truncation of the tidal recordings and extension of the period of ebb, as on recordings of low water of springs, would result.

## GROWTH

In an uncultivated fishery in equilibrium a high growth rate is not, of itself, of great importance. Since the term equilibrium implies that the crop is replaced as rapidly as it is harvested, the actual time taken for the crop to mature is not relevant. Certainly natural mortality takes its toll for a longer period, but evidence has been presented (Palenichko, 1948; Savilov, 1953; Baird, 1966) that, for a given species, increased growth rate is allied to an increased mean mortality rate and these two factors may well be compensatory in terms of yield.

However, in Britain the demand is for a large mussel, and, within limits, the larger the mussel the better the price. Walford (1946) has shown that the higher the growth rate of an animal the greater the ultimate length. Thus, to obtain mussels of a large size, a high growth rate is important. In addition, when mussels are cultivated and the area of cultivation is limited, or where a rent is paid for the ground, the higher the growth rate, the higher the yield per unit area in economic terms. There are, of course, other advantages related to high growth rate in mussels, such as an improved appearance of the shell and improved flesh quality (see section on Condition).

A series of experiments was made to follow the growth over a period of years. In some of the experiments mussels were used in bulk and random samples were taken to observe changes in the modal length of the population. In other experiments mussels in cages were used, and the growth of each mussel was measured.

In the experiments where the mussels were used in bulk, it was found that as new settlement occurred among them a new mode appeared and after about two years the mode of the new settlement had begun to merge with that of the original sample, making the results unreliable. In practically all the growth experiments the mussels used were from a "blanket" settlement which had occurred at about the 40% exposure level five or six years previously.

Measurement of growth in a natural population *in situ* was done in only one case, when a heavy sublittoral settlement occurred in one area. The growth of this settlement was followed up to the point where the random sampling became unreliable due to addition of mussels from a subsequent sparse settlement.

### GROWTH OF A NATURALLY-OCCURRING SUBLITTORAL SETTLEMENT

During a diving investigation in the comparatively deep water of the Deganwy Narrows (see Frontispiece), a blanket settlement of very small mussels was discovered at depths from about 20 to 40 ft (6 to 12 m)

below low water of spring tides. These small mussels, open and filtering, gave the appearance of a velvet carpet and were about 2 mm long when they were first discovered in August 1955.

Savage (1956) measured the growth of Conway mussels after the phenomenal spat settlement of 1940 which covered the whole of the Conway mussel beds. The mean lengths recorded by Savage for mussels collected near low-water mark and from the channel of the estuary are shown in Figure 8, with the mean lengths of the sublittoral settlement measured in this investigation superimposed. The mussels of the 1955 settlement are seen to have grown rather faster than those of the 1940 settlement; it would appear most likely that this difference was due to a density effect. Although the settlement in the Deganwy Narrows in 1955 was a blanket one, the total area of settlement was only about 400 yd by 200 yd (366 by 183 m) while the 1940 settlement studied by Savage covered the whole of the beds.

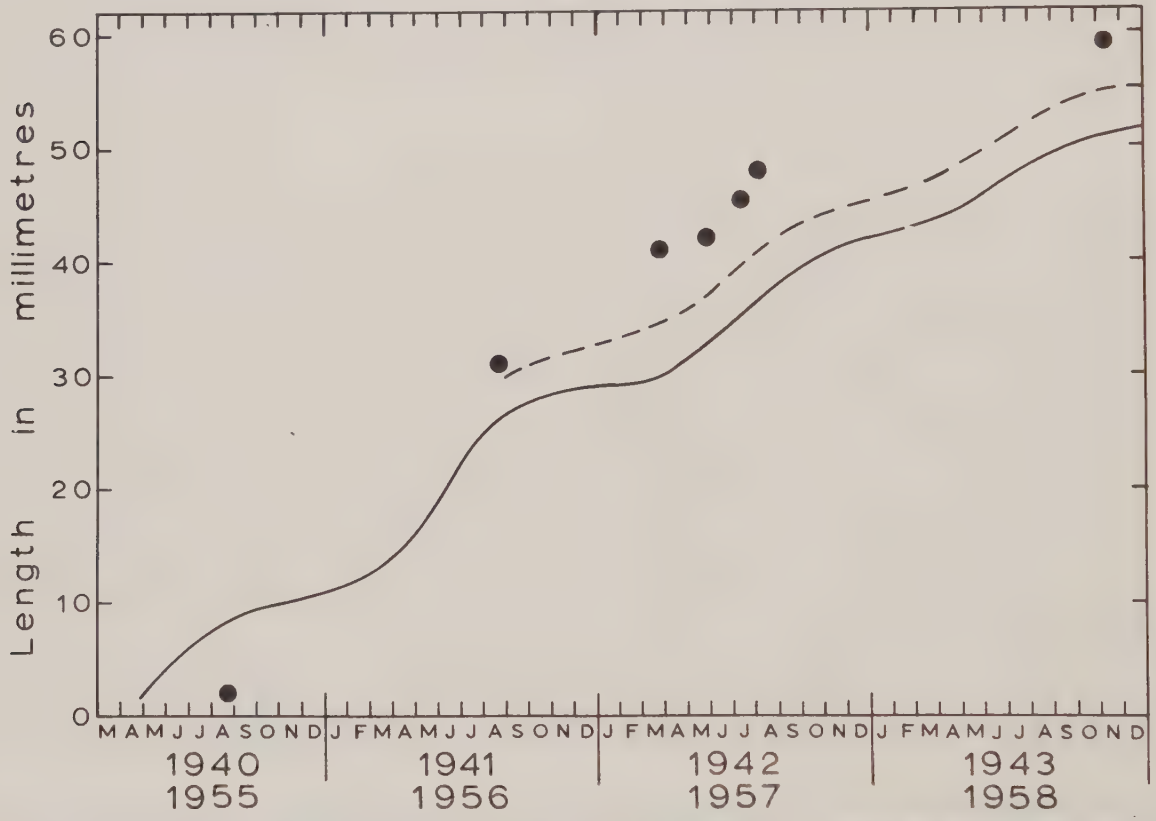



Fig. 8. *Growth in length of: sublittoral mussels from Deganwy Narrows*, 1955-8 (*dots*); *sublittoral mussels from the channel of the estuary*, 1940-3 (*broken line*) (*Savage* 1956); *bank mussels from the Scabs*, 1940-3 (*continuous line*)(*Savage* 1956).

## GROWTH ON BOUCHÔTS

An investigation into the factors governing the infection of mussels by the parasite *Mytilicola intestinalis* (Hepper, 1955) showed that in most cases the infection was much lighter in mussels raised off the bottom. In the Bay of Aiguillon (France) mussels are grown on vertical poles, or "bouchôts", upon which the mussel spat settles (Herdman, 1894; Lambert, 1935). Some of the mussels are later moved to fences to continue their growth. It is clear that placing mussels on a vertical structure in the intertidal zone must increase the proportion of the tidal cycle that they spend out of water, but it has nevertheless been suggested that the growth rate on the bouchôts is particularly high. Field (1911) had stated that mussels grown on

bouchôts in France had a higher growth rate than was found in mussels in England, but he did not quote the sources of his information or the tidal levels concerned. The experiment described below was set up to determine the difference in growth rate of mussels raised off the bottom and of mussels resting on the bottom *at the same tidal level.*

In March 1953 two fences were set up at the Deganwy Narrows, parallel to the water line. The base of the lower fence was 2 ft (0·6 m) below low water of a 28 ft (8·5 m) ordinary spring tide, and the top of the upper fence was 8 ft (2·4 m) higher (Figure 9). Low-water mark of a 28 ft tide (predicted height at Liverpool) was the datum point for this experiment.

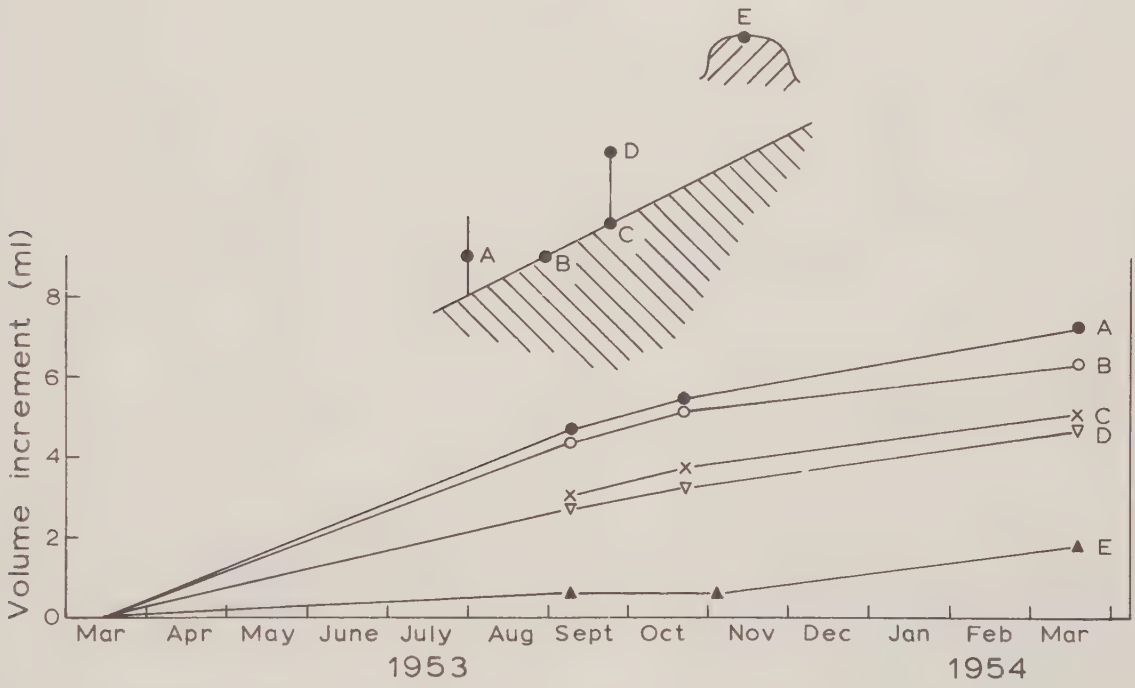



Fig. 9. *Volume increments of mussels on the fences at Deganwy.*
*A. On the lower rack, at the datum level (low water mark of a 28 ft tide.)*
*B. On the flat, at the datum level.*
*C. At the base of the upper rack (1¾ ft above A and B).*
*D. At a point on the upper rack 5½ ft above A and B.*
*E. At the original site of the mussels (11 ft above A and B).*

The fences were made of 6 ft (1·8 m) posts driven into the ground to a depth of nearly 2 ft (0·6 m) at intervals of 3 ft (0·9 m). Flexible poles were interwoven between each series of posts, and mussels from a high bank, 11 ft (3·4 m) above the datum, were attached to these fences. At the same time a sample of mussels from the same source was laid on the ground between the posts. Measurements of length and volume of the mussels were taken at varying periods from the datum level on the lower rack, from the datum level on the flat, from the base of the upper fence, and from a point on the upper fence 5½ ft (1·7 m) above the datum point (positions A, B, C and D respectively in Figure 9).

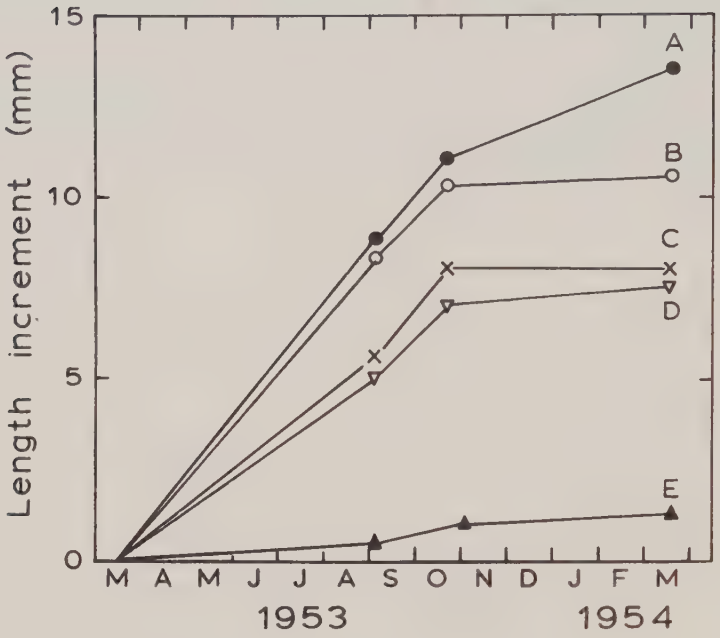



Fig. 10. *Length increment of mussels on the fences at Deganwy. Key as in Fig.* 9.

Table 1 sets out the observed modal lengths and volumes of the mussels, while Figures 9 and 10 show the increases in volume and length respectively over a period of a year. After this period the results began to be very erratic, due, it is believed, to new settlement. There was slightly better growth on the fence than on the flat at the datum level, but a gradually decreasing growth rate was apparent with the increase in height above datum level.

The mussels from the upper fence were heavily encrusted with barnacles, as was the fence itself. Collection of mussels from this fence was difficult because the mussels were firmly embyssed in the interstices of the weave. Growth of mussels on the fences $5\frac{1}{2}$ ft above low water of ordinary spring tides (position D) was slow, resulting in unattractive-looking mussels heavily encrusted with barnacles.

## GROWTH IN DIFFERENT PARTS OF THE ESTUARY

In mass experiments precise measurement of growth is difficult, due to the risk of sampling error and to the anomalous results which could be caused by unrecognized recruitment. Special experiments were therefore set up for this purpose in 1955, using 50 marked mussels which were kept in cages and examined at approximately two-monthly intervals until the end of 1956. In these experiments it was possible to identify individually a total of 50 mussels by using Roman numerals up to V, marking the left shell or the right shell, and using five different coloured paints. As not all the mussels were of exactly the same size, the mean growth increment was calculated, any dead mussels in the cages when the samples were measured being first discarded. The dead mussels — usually one or two in each cage — were replaced by other mussels from the same source as the originals, making the total up to 50 when the cages were replaced.

Table 1. *Modal length and volume of mussels on fences at Deganwy*

| Date | A | | B | | C | | D | | E | |
|---|---|---|---|---|---|---|---|---|---|---|
| | L.W.O.S.T. lower rack | | L.W.O.S.T. the flat | | Base of upper rack | | Top of upper rack | | Original site of mussels | |
| | Length (cm) | Volume (ml) | Length (cm) | Volume (ml) | Length (cm) | Volume (ml) | Length (cm) | Volume (ml) | Length (cm) | Volume (ml) |
| 16 Mar. 1953 | | | | | | | | | 4·16 | 7·73 |
| 8 Sept. 1953 | 5·03 | 12·46 | 4·98 | 12·03 | 4·70 | 10·92 | 4·66 | 10·48 | 4·22 | 8·30 |
| 22 Oct. 1953 | 5·27 | 13·18 | 5·19 | 13·07 | 4·95 | 11·56 | 4·85 | 11·0 | | |
| 3 Nov. 1953 | | | | | | | | | 4·27 | 8·30 |
| 19 Mar. 1954 | 5·51 | 14·91 | 5·21 | 14·05 | 4·93 | 12·85 | 4·92 | 12·52 | 4·27 | 9·42 |

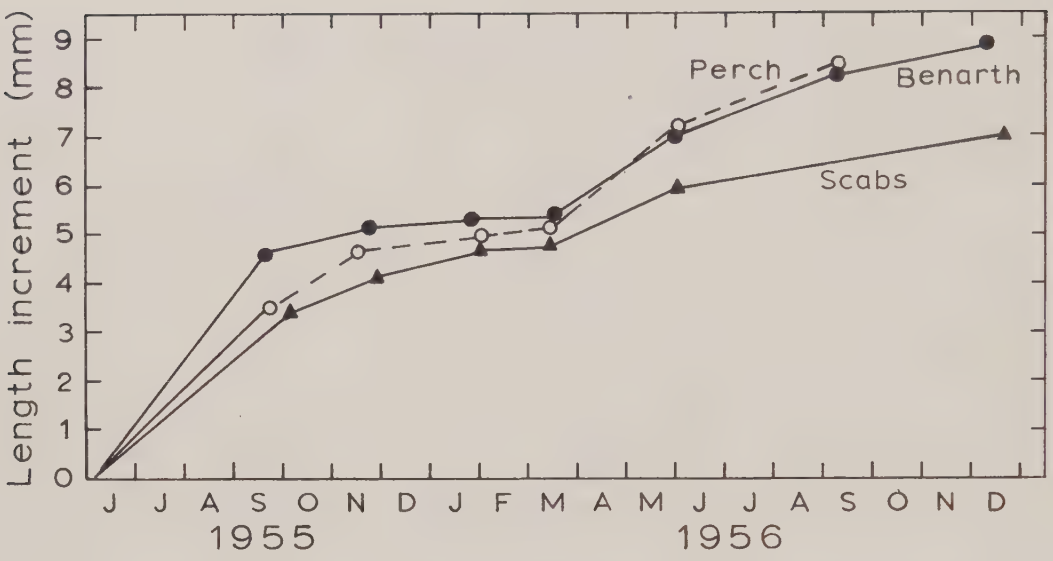



Fig. 11. *Growth in length of mussels in cages at the Scabs, the Perch and Benarth.*

It can be seen from the section on hydrography that salinity varied considerably from one part of the estuary to another at the same time on any particular day. Naturally, the higher reaches of the river had lower salinities and these lower salinities were maintained for longer periods. In order to determine whether the reduced salinities affected growth, four cages of 50 mussels were placed sublittorally at four points in the estuary. These were, in order of reduced salinity, Benarth Point (near the upper limit of mussels), Bodlondeb Point, the Perch and the Scabs (the most seaward point of naturally-occurring mussels in the estuary). All the cages were moored sublittorally with a line to the shore. They were all set at comparable depths and, as far as possible, in similar conditions of tidal flow. The cage at Bodlondeb was near a pleasant promenade and it was found that it was frequently disturbed; sometimes it was up on the beach and sometimes it had disappeared altogether. This station was finally abandoned. The mussels in each of the cages were taken from a bank fairly high in the intertidal zone. They were old, about 2 inches in length and of fairly uniform size, and were the result of one year's settlement. The mean length increments of the 50 mussels, each one of which was individually identified, are shown in Figure 11. It can be seen from this figure that the mussels at the two higher stations, Benarth and the Perch, had higher growth rates than the seaward sample at the Scabs. The seasonal growth pattern was also very different, in that the upriver mussels grew faster than the most seaward ones in the summer but more slowly in the winter. This can be explained by the fact that during the summer, when rainfall is minimal, the upriver mussels are not subjected to the long periods of reduced salinity to which they are exposed during the winter, and thus their feeding is not inhibited for lengthy periods as in the winter. It would also seem that during the summer months the supply of suitable food is better in the upper part of the estuary than in the lower reaches. In the winter, in addition to the reduction of salinity below the point at which mussels will feed, low temperature of the river water will result in further reduction of feeding rate. At the seaward end, the mussels will not be subjected to these low temperature and reduced salinities to such an extent, but on the other hand they will not have the advantages of the rich feeding available to the upriver mussels in the summer. The slightly poorer overall growth rate at the Scabs may be due to an exposure effect. Although the cages were all placed sublittorally, it was possible to find sheltered positions for the two higher samples, either in the tide shadow of rocky promontories or, at the Perch, in an eddy area of

low tidal flow. There was no way of placing the Scabs sample in a tidal shadow or eddy and it had perforce to lie in the main tidal stream. This may have had an effect on the growth rate, either by the rolling about of the cage at the end of its mooring line, or directly by the high rate of tidal flow itself. Being at the extreme seaward end of the estuary, the mussels were also more exposed to wave action during storms, and such exposure is known to reduce growth rate (Fox and Coe, 1943)

## GROWTH IN RELATION TO TIDAL LEVEL

To determine the growth rate in relation to shore level or tidal exposure, individually identifiable mussels in cages were used and the growth increment measured. Mussels from the same source as were used for the salinity experiments were again employed. These experiments, which lasted from August 1955 to December 1956, were done near the purification tanks, where mussels occur plentifully.

Four levels were chosen, each as far as possible having similar conditions of tidal flow. The upper cage was set 9 ft above the highest level of no exposure; this is approximately half-tide level and also about the upper limit at which mussels occur naturally. The other cages were set at 3 ft vertical intervals down to the level of no exposure, this being taken as the level of extreme low water of spring tides. These four levels correspond approximately to 52%, 38%, 20% and 1% exposure to air respectively. The linear growth at the end of a year, shown in Figure 12, was $2\frac{1}{2}$, 3 and 4 times as much for the 38%, 20% and 1% levels of exposure respectively, as it was for the 52% level of exposure. During a period of hot weather in August and the first half of September in 1955 the growth rates were 7, 9 and 12 times as much for the lower levels as they were for the upper level. Coulthard (1929) recorded a growth rate 16 times as high for low-level mussels as for mussels at about half-tide level during the summer months. The probable reason for this large difference in growth rate at different levels has been discussed elsewhere (Baird and Drinnan, 1957), but a brief outline of the theory will be useful here.

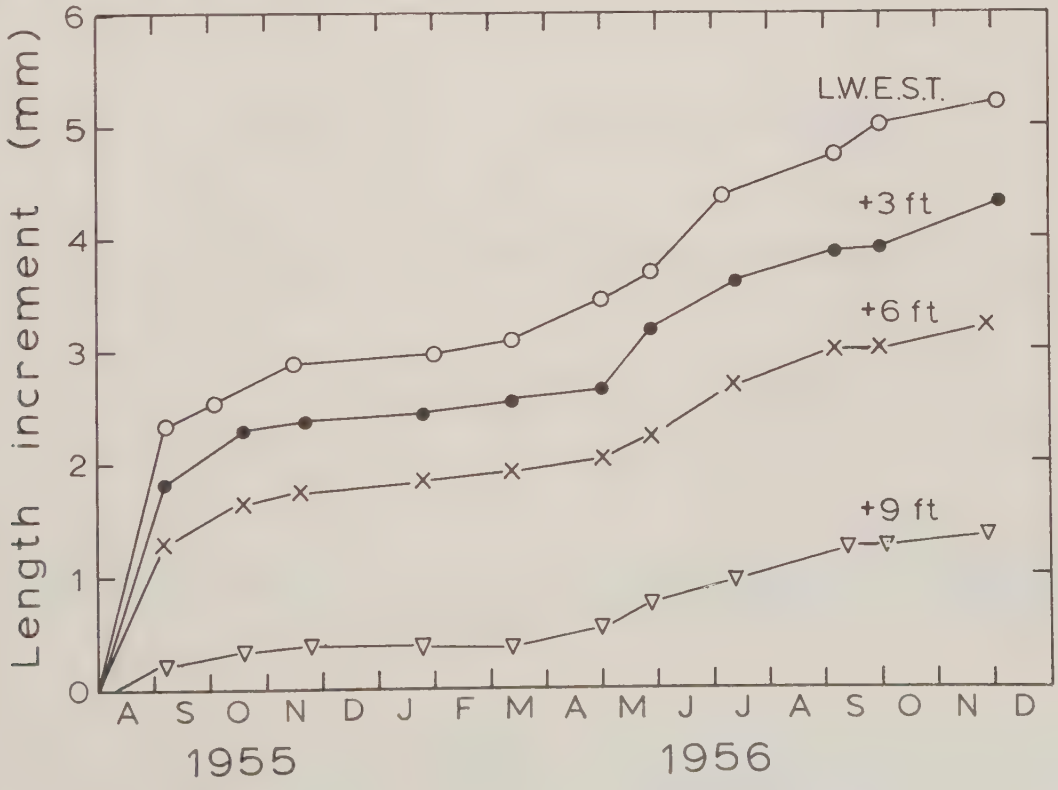



Fig. 12. *Growth in length of mussels at different tidal levels.*

In a given situation, if the proportion of time that the mussels were covered with water and could feed were the only factor affecting the growth rate, one would expect a mussel at half-tide level (50% exposure) to grow half as fast as a mussel which is continually immersed (100% feeding time). It has been shown by Baird and Drinnan, by Coulthard, and in the present paper, that this is not the case. Baird and Drinnan suggested that when the mussel was exposed, basic metabolism had still to go on, and this made demands on its reserves. If the mussel were not to decline, these reserves would have to be replaced when feeding recommenced. Naturally, the higher the air temperature, the higher would be the rate of basic metabolism of exposed mussels and the higher would be the proportion of the food required during the feeding period for replacing the energy used in the basic metabolic processes. It can be seen from Figure 12 that the difference in growth rate of mussels at the different levels is greatest during the periods of high air temperature. A point in the tidal zone would be reached where the basic metabolism consumed as much energy as was taken in during the feeding period available.

When the growth of mussels at different tidal levels was plotted and the curve extrapolated to the point of no growth (Figure 13) this point was found to be approximately at the 56% exposure level, which was in fact the limit of naturally-occurring mussels in this area.

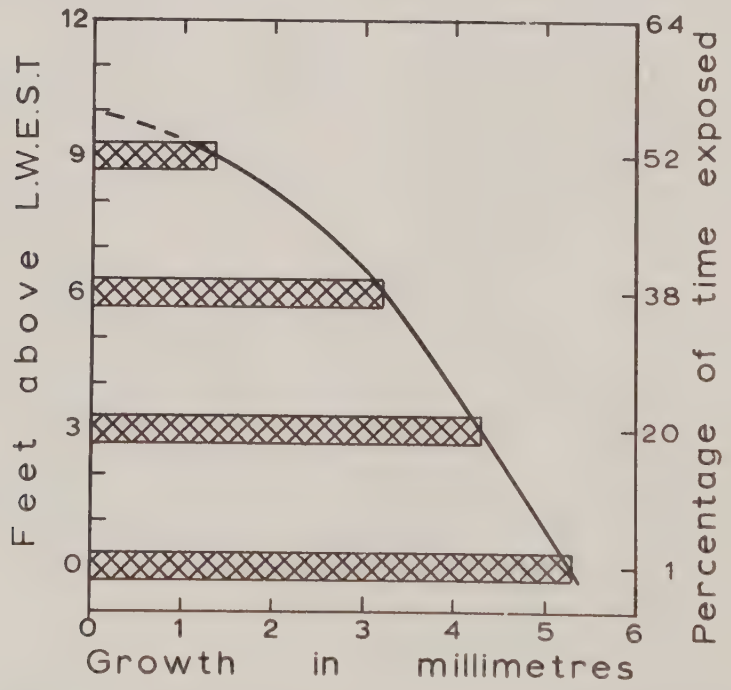



Fig.13. *Curve showing growth in length of mussels from August* 1955 *to November* 1956 *at different tidal levels, extrapolated to the point of no growth.*

## GROWTH RATE AND AGE

To find out whether it is more profitable to relay young mussels or old mussels of a given size, an experiment was set up to determine the difference in growth rate between them.

The older mussels were taken from the highest point at which they are found, while the younger mussels were dredged from a sublittoral area. (It can be seen from the preceding section that mussels high in the intertidal zone have a much lower growth rate than sublittoral mussels.) Both sets of 50 mussels were of a mean length of 4 cm. The mussels were marked and placed in a tray with two compartments. The tray had a woven wire bottom and a wire-netting cover, and was mounted in a sheltered area below the mussel tanks at about the level of low water. It can be seen from Figure 14 that the younger mussels had put on about twice the increment of the older mussels after a period of five months in the same environment. Thus, although the growth rate of old mussels is much increased by relaying lower in the tidal zone, it is still considerably less than that of young mussels indigenous to the zone. If young bank mussels are relaid fairly soon after settlement, they too might attain the high growth rate of the sublittorally-settled mussels.

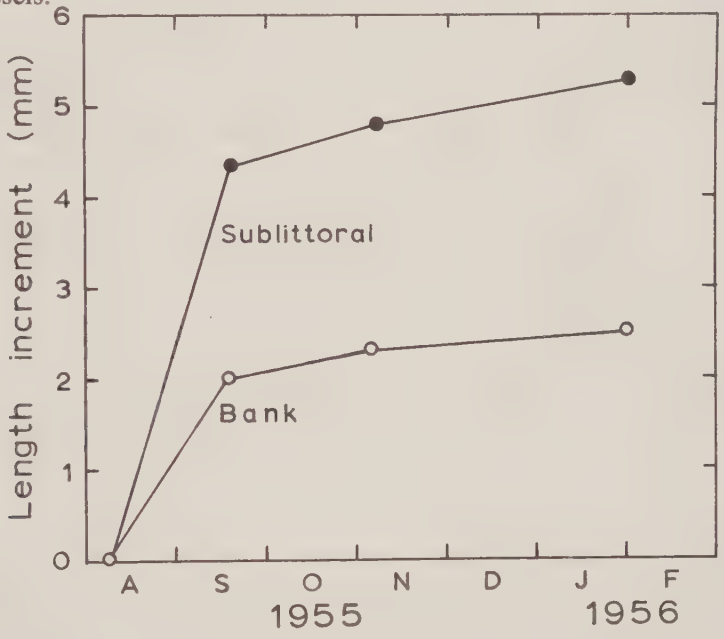



Fig. 14. *Growth in length of old (bank) and young (sublittoral) mussels when placed in a tray at low-water level.*

## SPAWNING

OBSERVATIONS were made at Conway during 1954 to determine the onset and duration of spawning of mussels.

Chipperfield (1953) gave the date of commencement of spawning at Conway in 1947 as between 10 and 14 May, with completion of spawning on 19 May. Savage (1956) reviewed the literature on this subject. In England and Wales spawning has been reported as early as March and as late as October. Although the peak of spawning seems to be in the late spring and early summer there is evidence that it goes on to some extent in at least eight months of the year.

### MATERIALS AND METHOD OF CLASSIFICATION

Samples were collected during the spring and early summer of 1954 from two stations which were just exposed at low water. The first station was at the seaward end of the main mussel beds which are on the

south side of the channel approximately half a mile west of the Perch, where the salinity is generally high. The second series of samples came from below the Mussel Purification Tanks, where the salinity is extremely variable. In all cases each mussel was examined individually and the gonad development was assessed by microscopic examination of smears from the inner surface of the mantle and classified as follows:

| Stage | Female | Male |
|---|---|---|
| I | Ova have no regular shape | Sperm non-motile |
| II | Ova have no regular shape, but a brownish area of granulation is visible within each | Sperm non-motile, but can be activated by placing in fresh seawater for 2–5 minutes |
| III | Ova tend to become spherical in shape; the brownish area of granulation is now more dispersed | Sperm motile |
| IV | Spent. The mussel is in poor condition; a few relict ova or sperm may be found in the mantle. | |

These stages correspond with the later stages of the classification used by Chipperfield (1953). His first two stages, viz. O and 1, were not used because the survey was not made during that part of the year when these stages occur, but his stage II was comparable to stages I and II in this report. Stages III and IV are similar in the two studies. At stage III it was possible to induce artificial fertilization. On fertilization the ova become spherical in shape.

The colour of the mantle in the female was found to vary from an orange or red-brown colour in the early stages, to an apricot colour in stage III. The male generally was much lighter, usually of a creamy colour. Chipperfield (1953) gives a good guide to the colouring of the mantle at the various stages of development.

Iwata (1952) found that spawning in *Mytilus edulis* could be induced by injecting M/2 KCl into the visceral cavity and also by electrical stimulation, which caused mussels with immature eggs to discharge an abundance of mature eggs within an hour. In the present work, therefore, at the same time as a check was made on the ripeness of the sperm and ova, a number of mussels were injected with 5 ml M/2 KCl; an exception was the sample collected on 2 March which was injected with 0·5 ml M/2 KCl. The solution was injected into the visceral cavity by means of a hypodermic syringe. After injection the mussels were stood, at room temperature, on a tray out of water for 30 minutes. Each was then placed individually into a glass bowl filled with fresh seawater at room temperature, and left overnight. On the following morning the presence or absence of sperm or ova in the water was noted. The ova appeared as a pinkish coloured mass on the bottom of the bowl, the sperm as a cloudiness in the water.

Table 2. *Numbers of mussels found in each stage of gonad development among those obtained from the main Morfa mussel beds at Conway*

| Date of sample | Female stages | | | | | Male stages | | | | | Sea temperature (°C) | Salinity at low water (‰) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | | I | II | III | IV | | | |
| 23 Feb. 1954 | 25 | — | — | — | | 75 | — | — | — | | — | — |
| 2 Mar. 1954 | 35 | — | — | — | | 62 | 3 | — | — | | — | — |
| 9 Mar. 1954 | 41 | — | — | — | | 9 | 50 | — | — | | — | — |
| 16 Mar. 1954 | 10 | 38 | — | — | | 9 | 43 | — | — | | 6·8 | 23·50 |
| 26 Mar. 1954 | 5 | 46 | — | — | | — | 49 | — | — | | — | — |
| 1 Apr. 1954 | 3 | 42 | — | — | | — | 55 | — | — | | — | — |
| 8 Apr. 1954 | — | 50 | — | — | | — | 50 | — | — | | 8·2 | 28·49 |
| 13 Apr. 1954 | — | 31 | — | — | | — | 63 | — | — | | — | 27·54 |
| 22 Apr. 1954 | — | 46 | — | — | | — | 54 | — | — | | 8·0 | 30·60 |
| 28 Apr. 1954 | — | 51 | 1 | — | | — | 48 | — | — | | 13·0 | 30·97 |
| 7 May 1954 | — | — | — | 12 | (48%) | — | — | — | 13 | (52%) | 9·1 | 28·26 |
| 10 May 1954 | — | — | — | 10 | (40%) | — | — | — | 15 | (60%) | — | — |

Table 3. *Numbers of mussels found in each stage of gonad development among those obtained from below the Mussel Purification Tanks at Conway*

| Date of sample | Female stages | | | | Male stages | | | | Sea temperature (°C) | Salinity at low water (‰) |
|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | I | II | III | IV | | |
| 10 Mar. 1954 | 22 | — | — | — | 7 | 1 | — | — | — | — |
| 17 Mar. 1954 | 20 | 4 | — | — | 1 | 25 | — | — | 6·1 | 7·84 |
| 29 Mar. 1954 | 29 | — | — | — | 1 | 20 | — | — | — | — |
| 13 Apr. 1954 | — | 29 | — | — | — | 21 | — | — | 10·5 | 5·16 |
| 22 Apr. 1954 | — | 25 | — | — | — | 25 | — | — | 8·9 | < 1·84 |
| 28 Apr. 1954 | — | 21 | — | — | — | 29 | — | — | 11·1 | 2·02 |
| 7 May 1954 | 1 | 24 | — | — | — | 25 | — | — | 8·8 | 9·52 |
| 11 May 1954 | — | — | — | 25 | — | — | — | 24 | — | — |
| 24 May 1954 | — | — | — | 5 | — | 15 | — | 4 | — | — |

Table 4. *Numbers of mussels that spawned as a result of the injection of M/2 KCl*

| Date | Number injected per sample | Spawning | | Date | Number injected per sample | Spawning | |
|---|---|---|---|---|---|---|---|
| | | Females | Males | | | Females | Males |
| | Morfa site (Mussel beds) | | | | Mussel tank site | | |
| 2 Mar. 1954 | 30 | 0 | 0 | 10 Mar. 1954 | 14 | 0 | 0 |
| 16 Mar. 1954 | 20 | 2 | 1 | 1 Apr. 1954 | 30 | 1 | 0 |
| 20 Mar. 1954 | 30 | 3 | 0 | 13 Apr. 1954 | 30 | 0 | 0 |
| 26 Mar. 1954 | 30 | 8 | 0 | 22 Apr. 1954 | 30 | 12 | 3 |
| 1 Apr. 1954 | 30 | 1 | 0 | 28 Apr. 1954 | 30 | 1 | 2 |
| 8 Apr. 1954 | 30 | 9 | 0 | 7 May 1954 | 30 | 1 | 1 |
| 13 Apr. 1954 | 30 | 0 | 0 | | | | |
| 22 Apr. 1954 | 30 | 5 | 4 | | | | |
| 28 Apr. 1954 | 30 | 4 | 1 | | | | |
| 7 May 1954 | 30 | 0 | 0 | | | | |

In Tables 2, 3 and 4 are shown the results obtained at Conway during 1954. It was found that during 1954 spawning took place between 28 April and 7 May on the Morfa mussel beds, some spawning being observed in the field when the sample was collected on 28 April. At the beds below the Mussel Tanks, whence most of the mussels examined by Chipperfield in 1947 were obtained, it was a little later, between 7 and 11 May.

The period of gonad ripening of mussels from the main Morfa beds was from about 16 March until 28 April in females, and from 9 March onwards in the males (Table 2). Below the Mussel Tanks, however, the period was later, as ripening in the female did not start until 13 April and in the male until 17 March (Table 3); it is possible that here the spawning may have been held back owing to the very low salinity immediately prior to 7 May, when it reached 9·52‰ at low water.

The sea temperature at the Morfa at the time of spawning had risen to 13·0°C, the mean air temperature at this time ranging from 5·6°C to 10·0°C. Below the Mussel Tanks the sea temperature at the time of spawning was 8·8°C; the air temperature at the time was 10·6°C on 6 May, fell to 8·3°C on 7 May, and rose sharply to 13·3°C on 9 May.

The results in Table 4 show that the attempt to induce spawning was not very successful and, although a number of spawnings was obtained, no peak occurred.

The females were generally less numerous than males in the smear samples. Although no record was kept of the male to female ratio in the injected mussels, it seems probable that most of the females spawned after injection. A sample taken from the mussel beds and injected on 16 March partially spawned in 24 hours. The mussels were still in good condition when opened, which suggests that from the middle of March many of the mussels only require quite a short period after stimulation to become mature. An artificial fertilization made with this sample resulted in straight-hinged veligers after 4 days.

It can be seen from the condition factor results in the next section of this paper that a fall in condition of mussels occurs during late winter and early spring. From the foregoing it would seem that this is not directly due to spawning, but may be associated with the development of gonads. Further declines in April and May 1956, March and April 1957, and in May 1958 are also shown; these may however have been due to massed spawning.

## CONDITION

The method used for the assessment of condition of the mussels examined in these experiments was that evolved at the Fisheries Experiment Station and described by Baird (1958). Except where otherwise stated, 60 mussels were gathered for each sample and these were grouped into four subsamples of 15 mussels each. The Condition Indices quoted are the means of these four subsamples and are the proportion of the shell cavity occupied by the meat, expressed as a percentage. It has been shown that the Condition Index varies with the size of the mussel (Baird, 1958), and for that reason, where comparative measures of condition were made, mussels of approximately the same mean size were used.

### SEASONAL VARIATION

To determine the seasonal variation in the Condition Index, samples were taken at approximately monthly intervals from the beach below the mussel tanks at a level of 8 ft above low water of extreme spring tides. This site is exposed to the air for 47% of the time and is one from which samples could easily be collected at neap as well as at spring tides. Samples were collected at shorter intervals when a sudden drop or peak of Condition Index was observed. The results are shown in Table 5 and Figure 15, in which the range of Condition Indices of the subsamples in each sample is indicated, to show the variation in the results.

The river water temperatures were recorded at the time of pumping at the mussel tanks at approximately high tide and are plotted in Figure 15 as the mean weekly temperatures.

Sampling started in June 1955, and subsequent samples showed the Condition Index to be rising. This rise flattened out in August and the Index stayed at a constant level until January 1956. There was an initial drop in February and March, then a rise before a drop to the lowest level in May. This pattern of Condition Index variation during February to July was repeated from June 1956 to January 1958, with the usual plateau at a little over 50% from August to January.

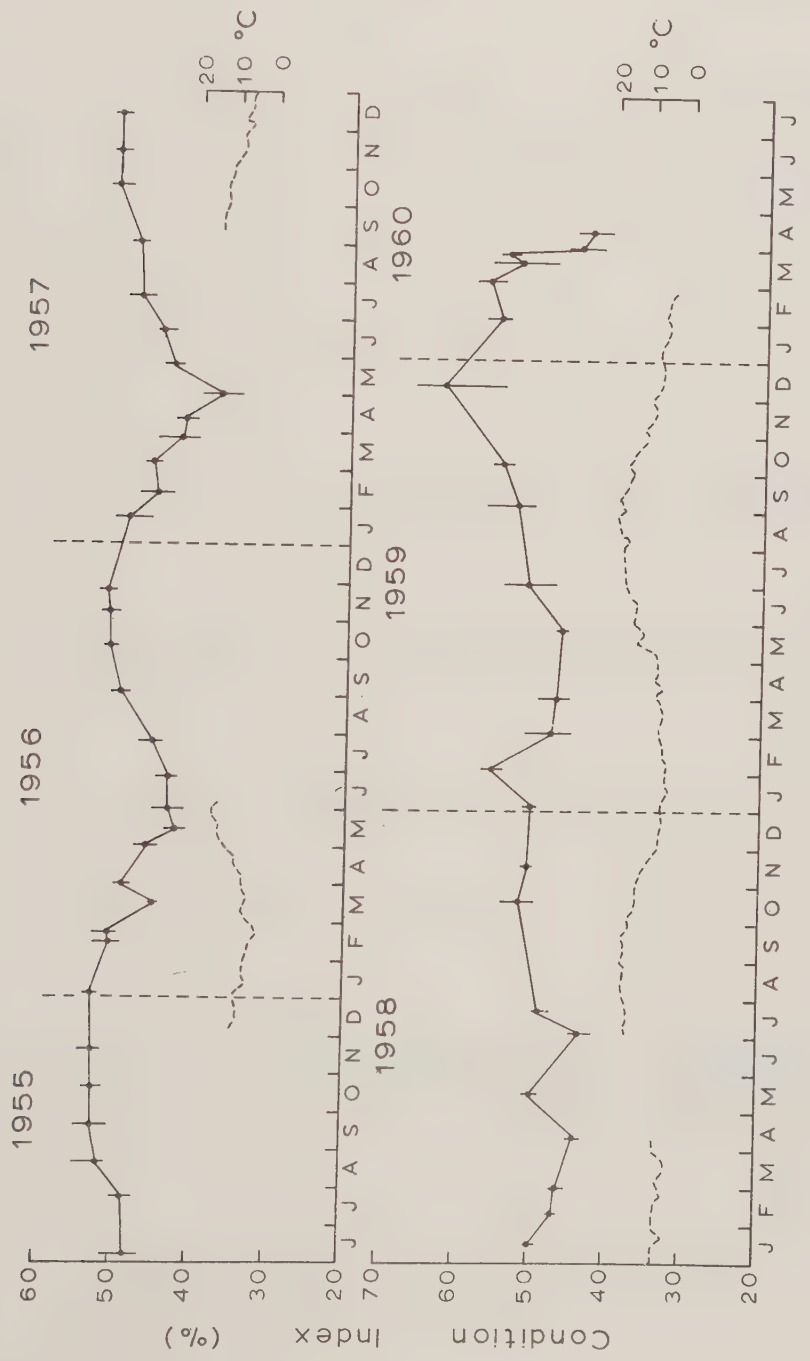



Fig. 15. *Condition Index of mussels collected from a position 8 ft above low water of extreme spring tides (47% exposure to air) below the Mussel Purification Tanks at Conway from June* 1955 *to April* 1960. *Mean weekly seawater temperatures at high tide at the tanks are indicated by broken lines. Each point is the mean of the four subsamples, (see text), and the vertical line through the point is the range of the Condition Index in the four subsamples.*

Table 5. *Condition Index of subsamples and mean Condition Index of mussels from below the Purification Tanks—*

| Date | Condition Index of subsamples | | | | Mean C. I. | Total number of mussels in sample |
|---|---|---|---|---|---|---|
| 1955 | | | | | | |
| 8 June | 50.8 | 47.2 | 45·8 | — | 48·0 | 50 |
| 25 July | 47·1 | 48·9 | 49·4 | 47·7 | 48·3 | 50 |
| 21 Aug. | 54.4 | 50·5 | 50·9 | — | 51.9 | 42 |
| 22 Sept. | 54·5 | 50·6 | 54·7 | 50·7 | 52·6 | 53 |
| 20 Oct. | 53·5 | 52·3 | 50·9 | — | 52·2 | 55 |
| 21 Nov. | 51·5 | 51·8 | 54·0 | — | 52·4 | 51 |
| 1956 | | | | | | |
| 3 Jan. | 53·1 | 53·1 | 53·0 | — | 53·1 | 53. |
| 15 Feb. | 53·0 | 49·2 | 50·3 | — | 50·8 | 51 |
| 20 Feb. | 52·4 | 49·6 | — | — | 51·0 | 30 |
| 16 Mar. | 44·2 | 45·2 | 45·5 | — | 44·9 | 54 |
| 29 Mar | 48·1 | 48·8 | 50·0 | 49·1 | 49·0 | 62 |
| 30 Apr. | 47·7 | 46·7 | 45·2 | 44·8 | 46·2 | 60 |
| 14 May | 40·9 | 43·8 | 41·2 | 43·2 | 42·3 | 57 |
| 31 May | 41·3 | 43·1 | 43·6 | 45·4 | 43·3 | 60 |
| 28 June | 42·2 | 44·3 | 45·0 | 43·6 | 43·3 | 57 |
| 25 July | 46·9 | 45·7 | 44·2 | 45·7 | 45·6 | 57 |
| 4 Sept. | 50·7 | 50·3 | 48·4 | 49·4 | 49·7 | 65 |
| 8 Oct. | 50·8 | 51·2 | 50·7 | 51·7 | 51·1 | 61 |
| 5 Nov. | 52·4 | 51·2 | 50·0 | 51·3 | 51·2 | 63 |
| 23 Nov. | 52·4 | 50·7 | 50·8 | 52·4 | 51·6 | 61 |
| 1957 | | | | | | |
| 21 Jan. | 50·9 | 49·4 | 49·1 | 46·0 | 48·8 | 62 |
| 13 Feb. | 43·2 | 47·6 | 45·4 | 45·7 | 45·5 | 60 |
| 6 Mar. | 44·7 | 46·4 | 46·8 | 46·5 | 46·1 | 60 |
| 28 Mar. | 45·3 | 40·6 | 41·9 | 40·0 | 41·9 | 61 |
| 11 Apr. | 42·9 | 40·3 | 41·2 | 41·4 | 41·4 | 60 |
| 1 May | 35·8 | 34·6 | 37·8 | 39·2 | 36·8 | 60 |
| 24 May | 41·9 | 44·3 | 44·3 | 42·4 | 43·2 | 62 |
| 21 June | 45·2 | 45·2 | 45·2 | 43·3 | 44·7 | 60 |
| 18 July | 47·6 | 49·2 | 46·1 | 47·1 | 47·5 | 60 |
| 30 Aug. | 47·2 | 47·4 | 48·4 | 48·7 | 47·9 | 61 |
| 14 Oct. | 51·5 | 51·4 | 49·1 | 51·5 | 50·8 | 66 |
| 11 Nov. | 49·6 | 51·6 | 50·8 | 50·0 | 50·5 | 65 |
| 11 Dec. | 51·2 | 49·3 | 50·7 | 51·3 | 50·6 | 64 |

Table 5. *Condition Index of subsamples and mean Condition Index of mussels from below the Purification Tanks— continued*

| Date | Condition Index of subsamples | | | | Mean C. I. | Total number of mussels in sample |
|---|---|---|---|---|---|---|
| 1958 | | | | | | |
| 14 Jan. | 48·8 | 49·6 | 50·0 | 49·3 | 49·4 | 62 |
| 10 Feb. | 46·1 | 46·9 | 47·3 | 46·3 | 46·6 | 60 |
| 28 Feb. | 45·3 | 46·4 | 45·2 | 45·8 | 45·6 | 60 |
| 9 Apr. | 43·3 | 44·4 | 44·4 | 44·4 | 43·8 | 63 |
| 14 May | 48·7 | 49·1 | 50·3 | 50·4 | 49·6 | 60 |
| 4 July | 41·8 | 43·5 | 44·4 | 43·5 | 43·3 | 61 |
| 22 July | 47·5 | 49·4 | 49·2 | 49·1 | 48·8 | 63 |
| 1 Oct. | 61·2 | 62·2 | 60·4 | 63·4 | 61·8 | 61 |
| 17 Oct. | 49·4 | 49·7 | 52·9 | 54·1 | 51·5 | 61 |
| 14 Nov. | 50·0 | 50·4 | 51·2 | 50·9 | 50·6 | 60 |
| 1959 | | | | | | |
| 2 Jan. | 49·7 | 50·4 | 50·4 | 51·2 | 50·4 | 60 |
| 4 Feb. | 53·8 | 55·7 | 56·7 | 56·3 | 55·6 | 60 |
| 5 Mar. | 47·9 | 46·6 | 45·6 | 51·3 | 47·7 | 64 |
| 31 Mar. | 49·2 | 45·9 | 45·3 | 48·4 | 47·2 | 60 |
| 25 May | 45·7 | 45·7 | 47·1 | 46·1 | 46·2 | 61 |
| 1 July | 53·4 | 48·9 | 54·4 | 47·4 | 51·0 | 62 |
| 3 Sept. | 53·1 | 50·4 | 56·7 | 50·3 | 52·6 | 60 |
| 6 Oct. | 54·7 | 55·9 | 53·8 | 53·4 | 54·4 | 61 |
| 7 Dec. | 65·9 | 65·1 | 60·3 | 54·6 | 62·3 | 102 |
| 9 Dec. | 65·4 | 65·3 | 61·8 | — | | |
| 1960 | | | | | | |
| 4 Feb. | 54·8 | 55·5 | 54·1 | 56·9 | 55·3 | 60 |
| 3 Mar. | 54·7 | 54·9 | 58·6 | 57·4 | 56·4 | 60 |
| 18 Mar. | 48·1 | 54·7 | 56·6 | 49·5 | 52·2 | 60 |
| 22 Mar. | 53·3 | 55·2 | 53·0 | 55·4 | 54·2 | 60 |
| 1 Apr. | 41·8 | 46·5 | 44·3 | 45·2 | 44·4 | 60 |
| 13 Apr. | 45·7 | 40·8 | 42·8 | 45·2 | 43·6 | 60 |

In 1958 the initial fall in condition was gradual, with a recovery in May followed by a further steep drop in June. A high peak of condition (62%) was reached at the beginning of October. Condition then dropped again to the plateau level, with a further peak in February 1959. This was followed by the usual seasonal decline during March and April, with a slow recovery to the exceptionally high level of 62% in December. A decline to the plateau level followed. When this high peak was observed in December 1959, the range of Condition Index for the subsamples was from 54 to 66%, with a mean of 61%. A replicate sample was taken and examined two days later, and the range of Condition Index extended from 61 to 65% with a mean of 64%. The mean of these two samples was plotted in Figure 15.

Gonad examination carried out in 1954 at Conway showed that mature ova and sperm were not present until late April and early May. Chipperfield (1953) states that for the years 1946-7 spawning of Conway mussels from the main beds began in late May and was completed in early June, covering a period of nine days. In March and April 1960, although the Condition Index had dropped from the peak of December 1959, gonad examination showed that the ova and sperm were still at stages I or II with very few at stage III. The relation between Condition Index and gonad development of mussels would seem to be a field worthy of further investigation.

Mussels from below the tanks are about $\frac{1}{4}$ mile below the upper limit of mussel distribution in Conway; they are subjected to lower salinity during winter and more extremes of water temperatures than are mussels on the main beds, and these factors may have an effect on Condition Index. Whether a similar pattern of variability in Condition Index occurs in mussels from lower down the Conway estuary or in mussels from other areas is not known.

## EFFECT OF TIDAL LEVEL

When the Condition Indices of mussels from different tidal levels were compared it as found that the Indices decreased as the exposure to air increased. Baird and Drinnan (1957) found th for a given length the meats of mussels periodically exposed to air were smaller than the meats of sublittoral mussels.

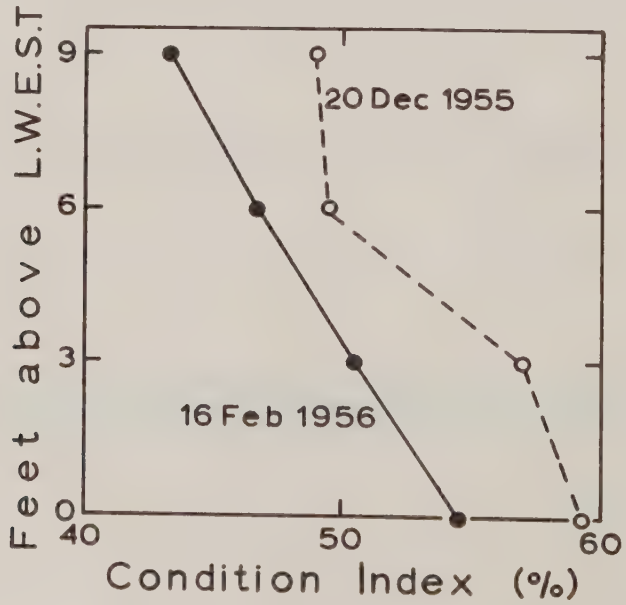



Fig. 16. *Condition Index of mussels from different tidal levels in the Conway estuary examined on* 20 *December* 1955 *and* 16 *February* 1956.

To study this effect more closely samples of mussels of the same size range were collected and examined on 20 December 1955, from tidal levels of 0, 3, 6 and 9 ft above low water of extreme spring tides, corresponding to 1%, 20%, 38% and 52% exposure to air respectively. This experiment was repeated on 16 February 1956, and the results of the two are shown in Figure 16. The same inverse relationship between Condition Index and exposure was found on both occasions, though the values were all lower in the later

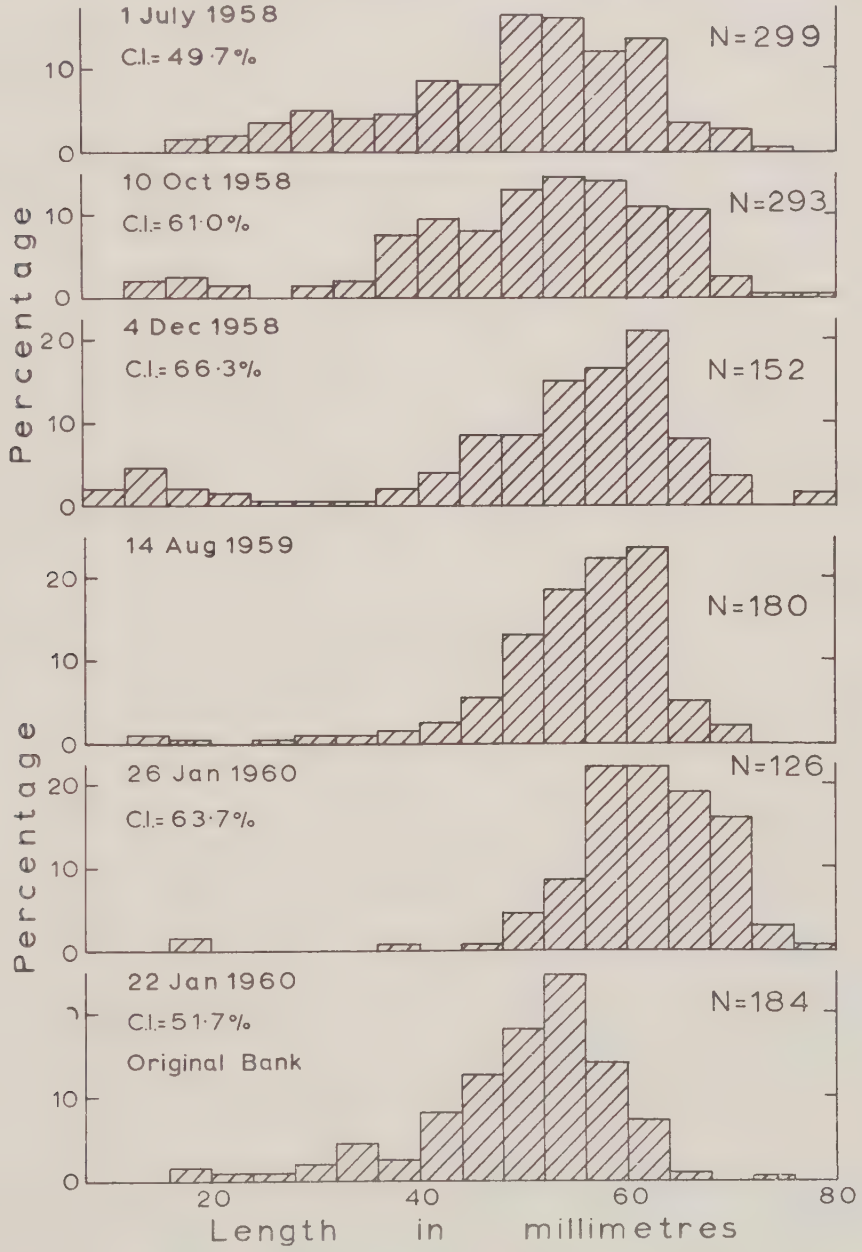



Fig. 17. *Histograms showing increases in length of mussels relaid on* 1 *July* 1958 *from the Bangor Flats onto a plot in the River Ogwen.*
*N* =*Number in sample.*
*C.I.* =*Condition Index.*

experiment. The difference is probably connected with the seasonal variation in Condition Index observed during the examination of monthly samples of mussels taken from below the mussel tanks. A slight fall in Condition Index was noted between the samples examined in November 1955 and February 1956 (Figure 15).

In November 1958 one ton of sublittoral mussels dredged from Deganwy was laid at a level of 12 ft above low water of extreme spring tides, where there was exposure for approximately 65% of the time, in connection with experiments to find the survival rate of mussels in air after conditioning by tidal exposure. At the time of relaying, the Condition Index of these mussels was 57% with a range from 56% to 58%. After three days' tidal exposure the Condition Index had fallen to 55% with a range of 54% to 55%. Subsequent examination showed that the Condition Index remained at this level and at the end of 31 days of tidal exposure the Condition Index was still 55%. This is remarkable in view of the observations that mussels growing at half-tide level had a Condition Index of 49%.

### EFFECT OF RELAYING

In connection with work on the bulk relaying of mussels (see below) about 40 tons of mussels were moved on 1 July 1958 from beds on Bangor Flats to a lower level in the channel of the River Ogwen. During a period of five months the Condition Index rose from 50% to 66% whilst that of the controls remained at about 50%; an increase from 50% to 61% was achieved in the first three months (Figure 17).

Later on, mussels were dredged off the original banks and laid on to four plots in the Menai Straits, one above and one below low-water mark at Gallow's Point and two below low-water mark at Siliwen. In all instances, on subsequent examination of these relaid mussels a considerable increase in Condition Index was found to have occurred.

When slow-growing mussels of marketable size but of poor Condition Index are relaid into more favourable conditions, they soon attain a good Condition Index and shortly afterwards can be gathered and marketed.

## NOTES ON BULK RELAYING

In Holland, the home of "flat cultivation", mussels are laid on a bottom of muddy sand at a density of 12½ tons per acre in tidal flows of up to 2 knots (Lambert, 1935). After they have grown to market size the density is about 37½ tons per acre. Small-scale experiments in bulk relaying were done at Conway and Bangor in 1958, and in the Wash in 1954. The experiments were designed to measure improvement in condition and growth rate after relaying, and to assess the type of bottom on to which mussels could be laid and the extent to which bottoms could be stabilized by dense relaying. In addition, it was hoped to determine the rate at which mussels could be moved by power dredging.

### THE WASH

For the work in this area the Ministry's oyster dredger WYSTRYS was moved up to Boston from Burnham-on-Crouch. The WYSTRYS, a 45 ft boat powered by a diesel engine, was rigged at the time with a gallows over the stern from which two 3 ft standard oyster dredges were towed. She was worked on this occasion with a crew of four.

The mussels used in the Wash were from a large bank lying on the Toft Sands above the level of low water of neap tides; they were in loose clumps on a substratum of soft mussel mud. A consistent dredging rate of 3 tons per hour was attained with two dredges, and the dredged mussels were relaid at about mean

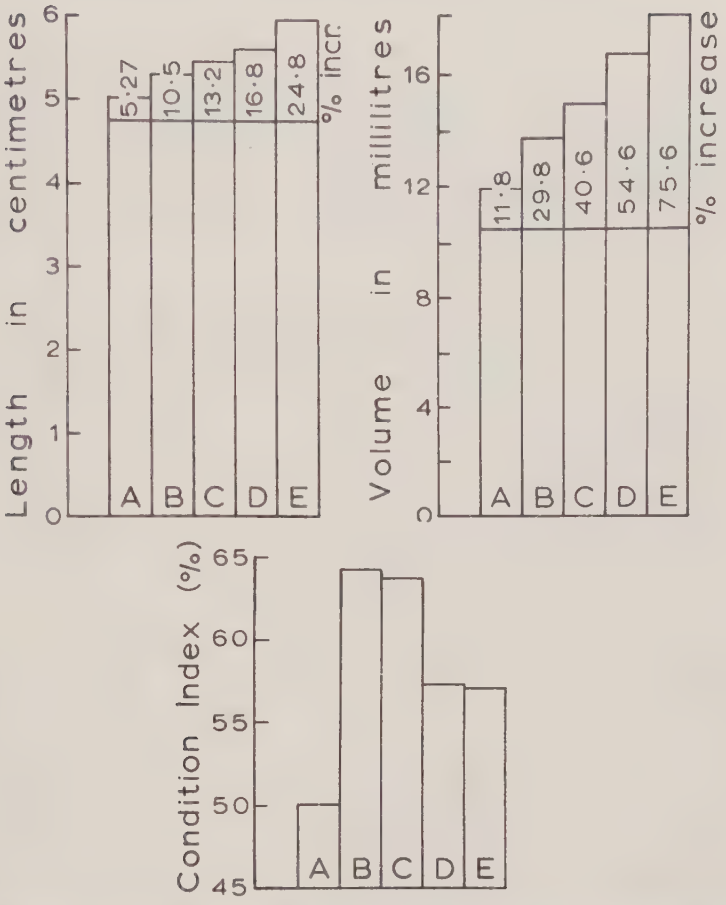



Fig. 18. *Diagram showing the increase in length and volume, and the Condition Index, of mussels at Toft Sands (The Wash) in October* 1954, *after relaying in May* 1954.

*A. Toft Sands bank mussels not moved from the original level of about low water of neap tides.*
*B. Mussels moved to low water of ordinary spring tides at Toft Sands.*
*C. Mussels moved to low water of extreme spring tides at Toft Sands.*
*D. Mussels moved to low water of ordinary spring tides at the Lays.*
*E. Mussels moved to low water of extreme spring tides at the Lays.*

low water of spring tides in the same area. The bottom on which they were laid was of muddy sand, very similar to the type of bottom used for relaying in Holland. Some of the mussels were also relaid at the Lays, an area near the entrance to the Boston Cut. The Lays extended from low water of ordinary spring tides to low water of extreme spring tides. The transplantation was done in May 1954, and in the following October samples were collected for measurement of increase in length and for assessment of condition. Figure 18 shows the results in diagrammatic form.

While the control sample from the bank had increased in length by only 5·27% and in volume by 11·8% mussels relaid at extreme low water in the same area had increased by 13·2% and 40·6% in length and volume respectively. The mussels relaid at the Lays at low water of extreme spring tides had increased by 24·8% and 75·6% in length and volume respectively. In each case relaying had improved the Condition Index from 50%, for the control mussels on the bank in October, to 64% for mussels relaid at low water at the Tofts and 57% for mussels relaid at the Lays.

It can be seen that while transplantation to lower tidal levels improved both growth rate and condition at both the Toft Sands and the Lays, the mussels relaid at the Tofts improved more in condition than

those at the Lays but did not grow as much. An area of fast growth is not necessarily also a good fattening area, though why this should be is not understood. Lambert (1951) associated deeper water (c. 20 ft at low water of spring tides) with fattening, and shallower water (below low water of spring tides) with growth. The Tofts and the Lays samples were at the same tidal level, the main noticeable difference being that the Lays mussels were in a more sheltered position and subject to slightly reduced salinity from time to time.

## CONWAY AND BANGOR

For the bulk relaying at Conway and Bangor in 1958 the Ministry's launch MYTILUS was used. This is a 25 ft open launch with a 16 h.p. diesel engine; she has a crew of two. The boat was converted for dredging by lining the hold and fitting a car back-axle winch. The mast was well stayed and a strong, free-swinging derrick was fitted, from which the dredge was towed. One 3-ft Baird dredge, with a bottom-opening gate, was used for all the dredging operations. A dredging rate of between 2 and 3 tons per hour was achieved on the intertidal mussel banks; this rate is relatively higher than that achieved on the WYSTRYS with two dredges. The difference may be accounted for partly by the fact that a more modern dredge was used on the MYTILUS and by the greater experience of her crew in its use.

At Conway the ground suitable for lays within the mussel fishery proper is very restricted. At the low-water level the remaining channel is narrow and steep sided. Only beyond the Scabs near the Morfa is there an area of flat ground at the low-water level. This ground is of fine clean sand, and, although apparently fairly stable, it is obvious that considerable scour occurs. To determine whether this sand could be colonized by fairly dense and extensive laying of mussels, 20 tons were dredged and laid in an area, 40 yards by 40 yards, in a gully which retained about six inches of water at low water of spring tides. The growth of these mussels is shown in Figure 19. As had been hoped, the dense laying resulted in the formation of a low mud bank which overlaid the clean sand and attained a height of about one foot in a year. The area is fairly exposed, and, later, as the mud bank increased in height, some of the mussels were dislodged from the mud during storms and were lost. However, the experiment showed that it was possible to lay successfully on fine clean sand and that the bottom could be stabilized.

At Bangor there is a large area of flat ground suitable for relaying and much more extensive lays were put down. Forty tons of mussels were laid in the Ogwen River at a depth of about 3 ft at low water of spring tides on a gravelly bottom in an area of 40 yards by 80 yards. This bottom was effectively stabilized, and, in a tidal flow of more than 2 knots, mussel mud formed to a height of about 3 ft. Growth and condition of these mussels is illustrated in Figure 17.

At the other extreme, mussels were laid on very soft flocculent mud (into which a man would sink up to his thighs) to the south of Gallow's Point on the Anglesey shore. The mussels were laid in the intertidal zone so that they could be observed. It was found that these mussels rested upon the mud and, as far as could be observed, none were lost. Again the mussels were laid at sufficient density for them to be able to embyss to each other and so form a mat. No difficulty has been encountered in dredging on these various substrata.

It is apparent that, provided the laying is sufficiently extensive to reduce edge effect and produce a large plateau, and sufficiently dense to allow the mussels to attach to each other and form a carpet, a great variety of bottoms can be stabilized.

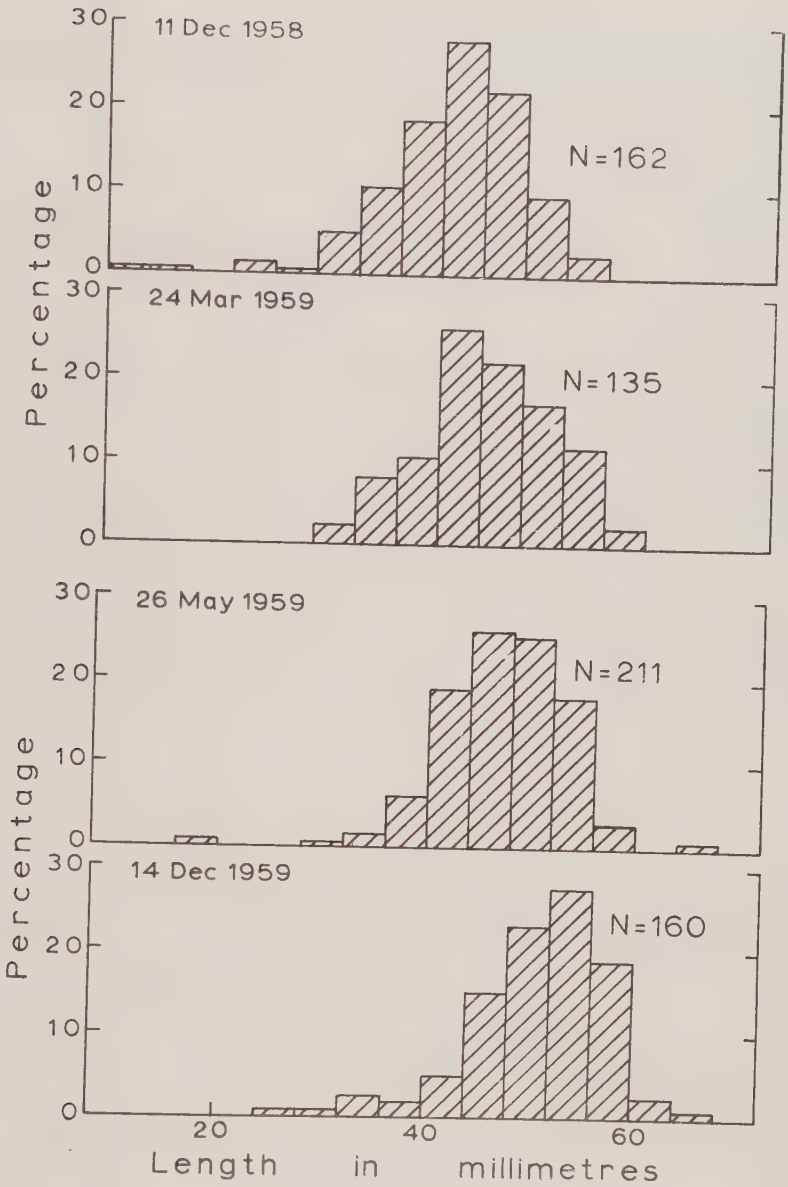



**Fig. 19.** *Histograms showing increases in length of mussels relaid at the Morfa, Conway on* 11 *December* 1958 *and re-examined on* 24 *March* 1959, 26 *May* 1959 *and* 14 *December*, 1959.
*N = Number in sample.*

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## SUMMARY

THE experiments and observations described and recorded in this paper were made during a study of the growth and fattening of mussels under a variety of estuarine conditions, with a view to applying the results to the development of the large-scale cultivation of mussels by relaying them at or below low-water mark.

Much of the work was done in the Conway estuary and a description is given of the hydrographic regime and the salinity changes that occur in that estuary.

The laying of mussels at different tidal levels and different positions in the estuary showed that the growth rate was inversely related to the amount of exposure to the air, and that in summer the mussels higher up the Conway estuary grew faster than those nearer to the mouth, the reverse occurring in winter. While old slow-growing bank mussels grew much faster when relaid at lower levels, they did not attain the growth rates of young mussels of the same size already living at the lower levels or similarly relaid.

In 1954 the time of spawning was studied by gonad smears and injection of KCl, and in that year spawning was found to occur on the main beds over a short period at the end of April and beginning of May. Spawning occurred a little later further up the estuary.

A study over several years of the seasonal changes in the Condition Index of mussels (expressed as the percentage of the internal volume of the shell filled with tissue) showed that this index remained high between late autumn and the end of January but fell to a minimum in about May. Condition, like growth, was inversely related to the degree of exposure to air.

Experiments made at Conway, in the Menai Straits and in the Wash, in which considerable quantities of mussels were taken from high levels and relaid at or below low water of spring tides, showed that substantial increases in growth and improvements in condition could be obtained by such relaying.

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(Frontispiece) *Fishing for cockles by 'scrape' and rake on Llanrhidian Sands*

*Photo: by courtesy of 'The Guardian'*